From melt pool to strength – Capabilities and limitations of ICME methods in case of AM

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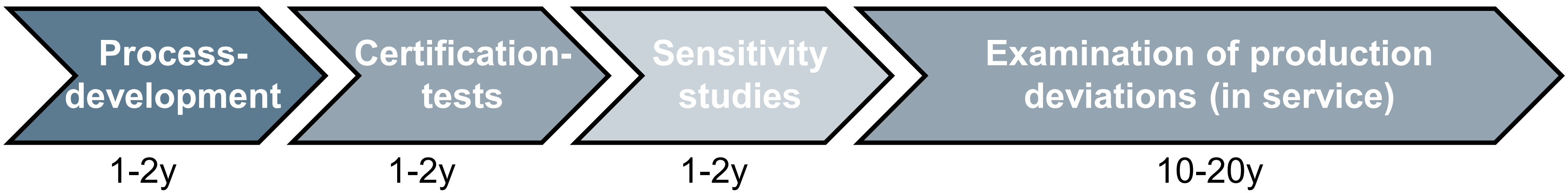
MTU Aero Engine AG, 14. April 2016

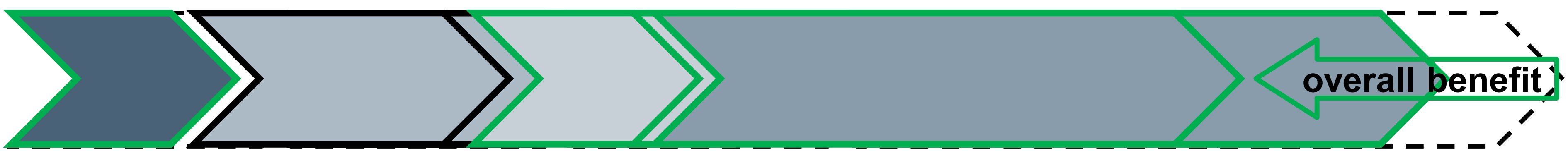
Need for ICME

Standard-Work (frozen processes)



ICME-Potential

€: ROI 5:1
t: - 20-30 %



- Stable process windows
- Optimized product properties
- …

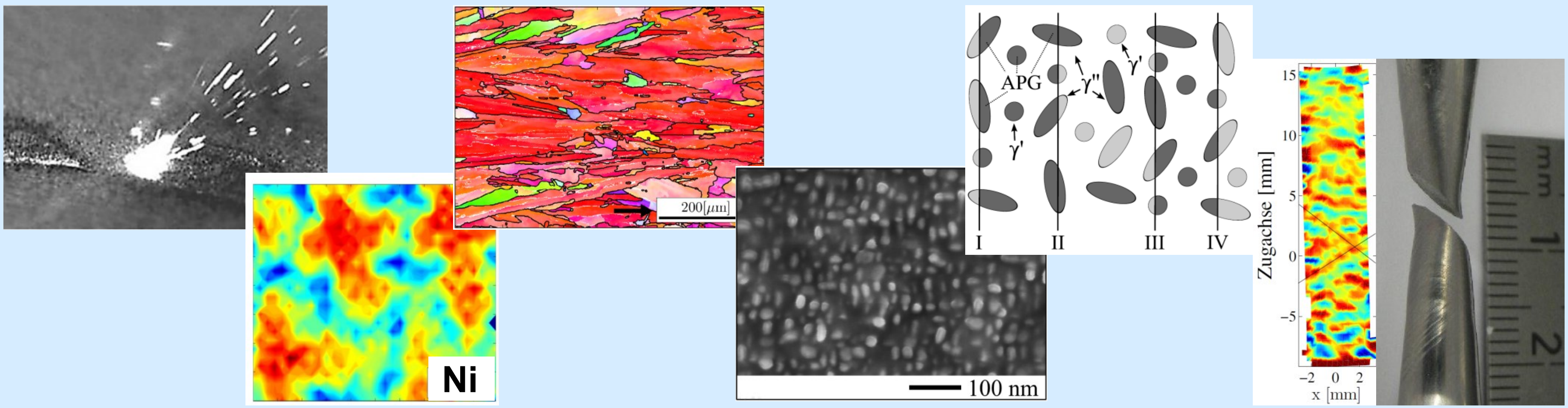
- Simplified sensitivity studies
- Earlier product introduction
- …

- Simplified deviation evaluation
- …

ICME Implementation Study, The Minerals, Metals & Materials Society, Warrendale, 2013

➢ **Situation:** well known material <> new manufacturing process

Process + Material → **Heat Treatment** → **Strength**



➢ **Problem:** high complex process chain with relevant effects on different length and time scales

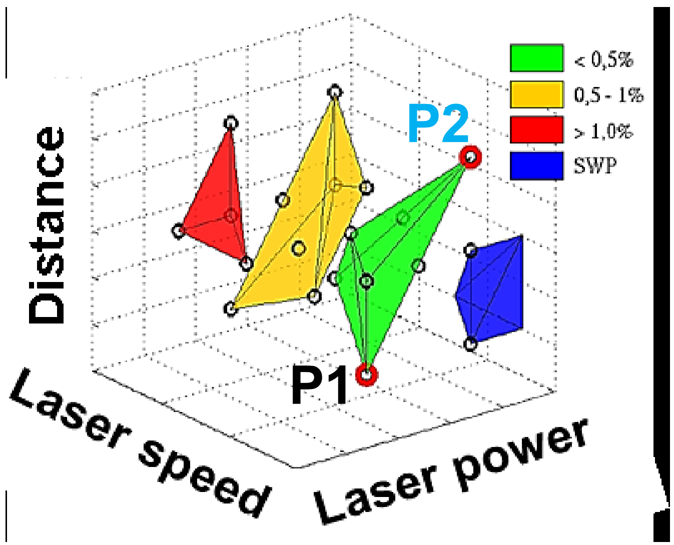
➢ **Core Question:** How can this process development task be solved in an optimum way?

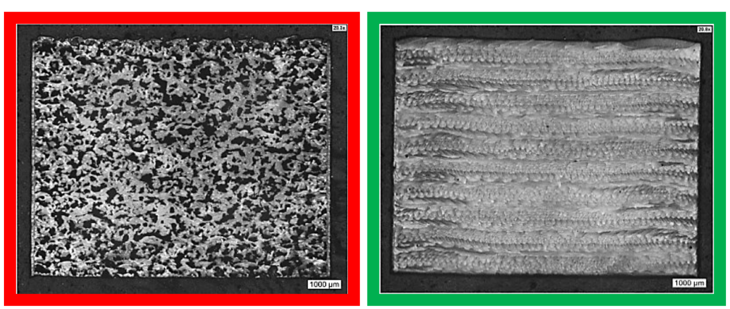
How can this development task be solved in an optimum way?

1. **Identify the process complexity.**
2. Develop a simulation chain along the whole manufacturing process as an enabler
3. Review capabilities and deficits of the simulation chain …

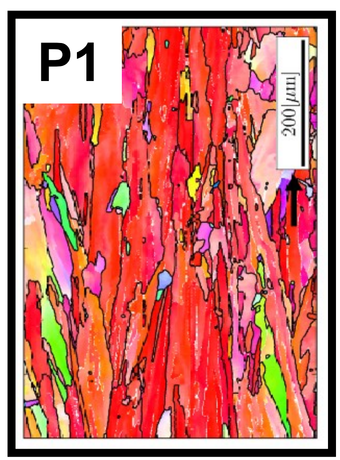
1. Identify the process complexity.

- **Safe process window**

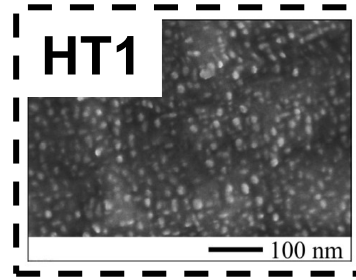


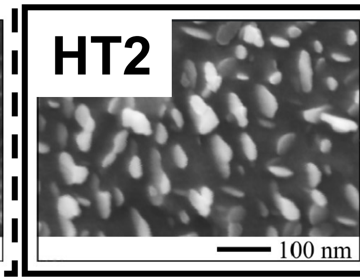


- **Adjustable texture**

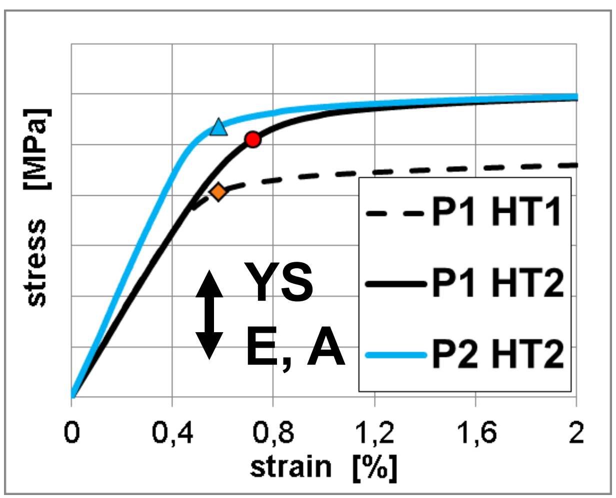


- **Aging effect**





- **Final strength**



How can this development task be solved in an optimum way?

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3. Review capabilities and deficits of the simulation chain

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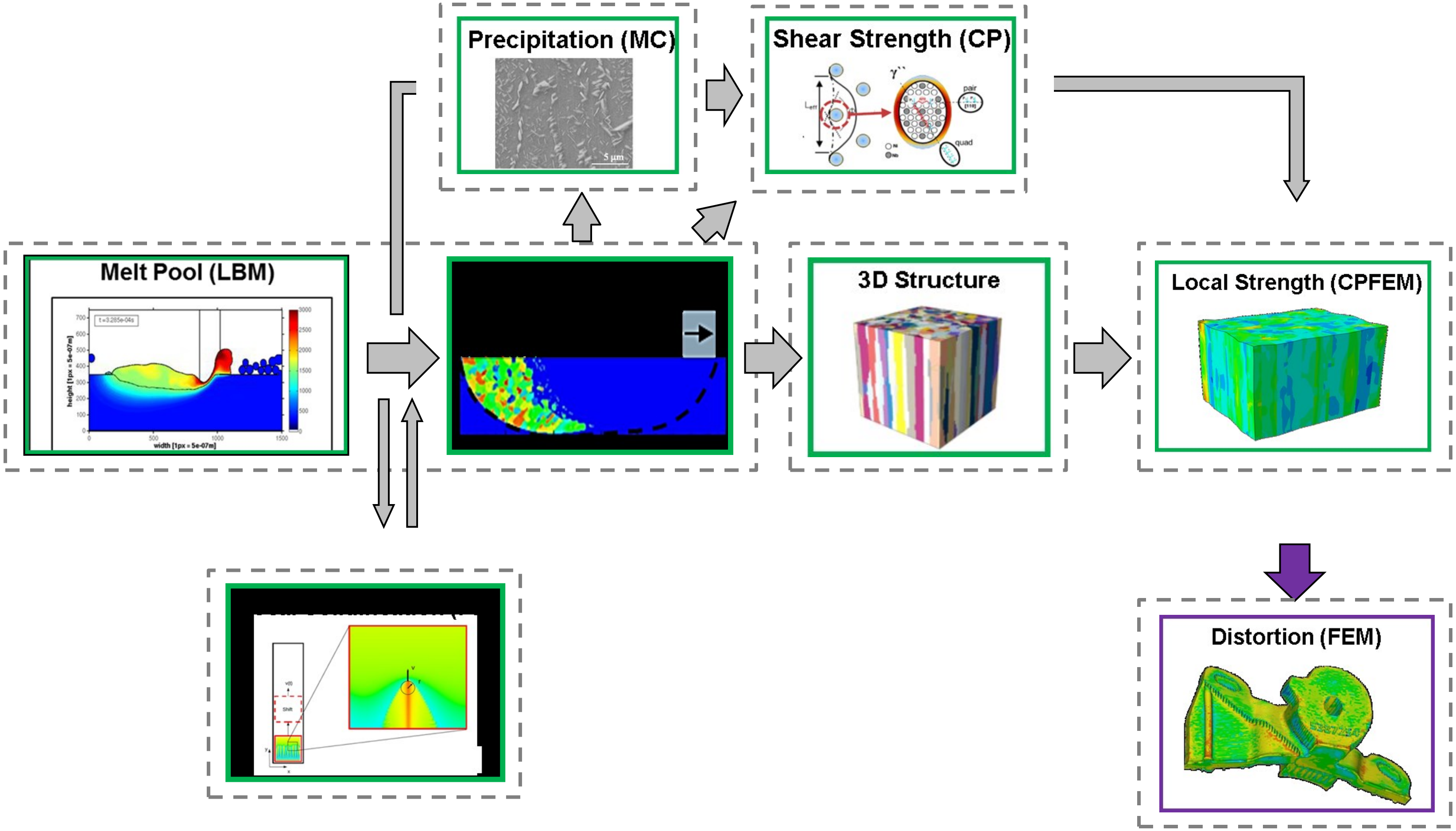

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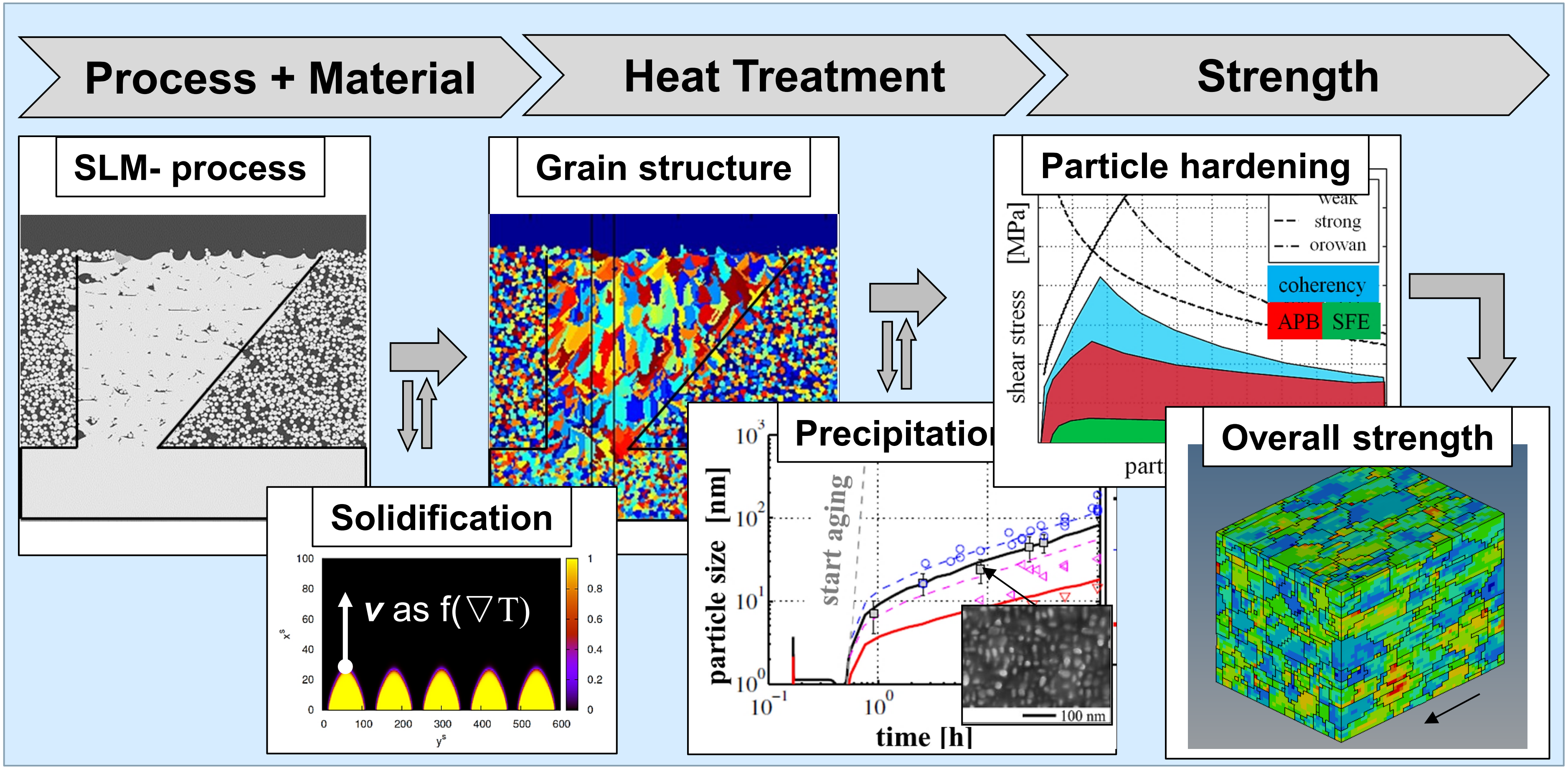

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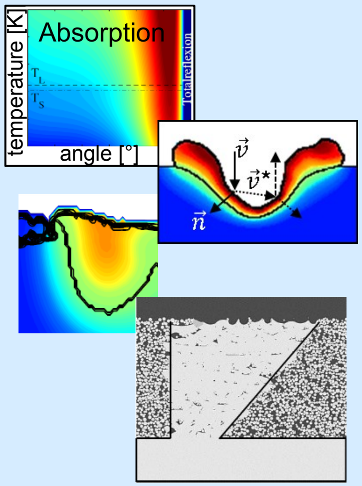
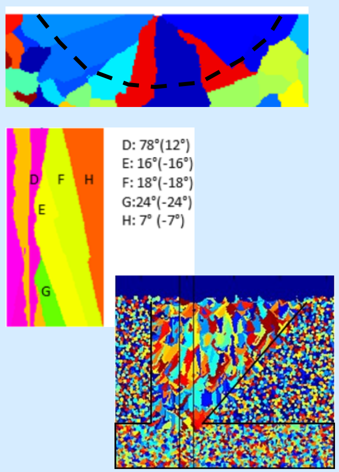
SLM- process



capabilities:
+ energy input
+ melt pool size
+ temperature range
+ defect density

Deficit:
- 3D fluid flow
- 3D temperature field
- powder bed dynamic

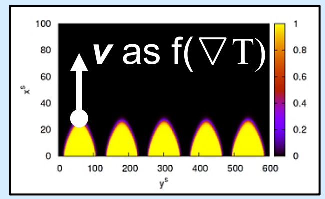
Grain structure

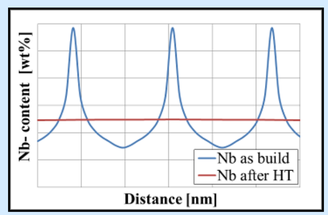


capabilities:
+ epitaxial growth
+ grain selection
+ multi grain particle
+ full coupled to melt

Deficit:
- 3D grain growth
- 3D grain orientation
- as build→heat treat

Solidification

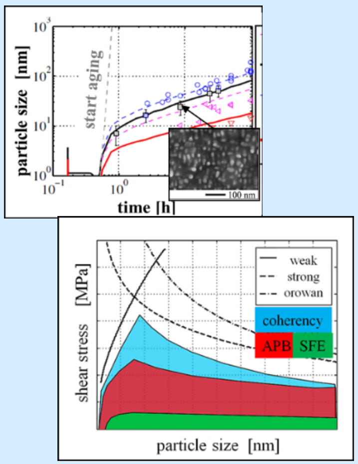




capabilities:
+ multi component
+ growth velocity
+ arm spacing
+ homogeneity

Deficit:
- Complex setup
- Not jet fully tested

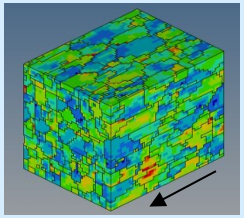
Precipitation

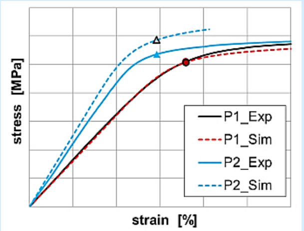


capabilities:
+ multi component
+ phase fraction
+ particle size
+ particle hardening

Deficit:
- No local resolution
- Uniform material

Overall strength





capabilities:
+ stiffness
+ anisotropy
+ texture effects
+ hardening effects

Deficit:
- RVE cell

Summary

Tools

Commercial

- MatCalc, ThermoCalc, Dictra
- Abaqus, Matlab

Own- or Academic-Development

- Calculix
- Dream3D, Paraview
- Lattice-Boltzmann
- Cellular Automata
- Phase-Field

ICME-Partners for SLM Simulation

Fraunhofer IWM, MPS, MatCalc, Thermo-Calc Software www.thermocalc.com

Acknowledgement

Bundesministerium für Wirtschaft und Energie

Clean Sky

Lessons Learned

During Development:

- Multi scale modelling functioning only by transferring key parameters between each tool
- Is a full integral simulation chain possible / useful because of different length & time scales?
- 3D models are unavoidable for some effects BUT: high complexity, high calculation effort
- Define simple test cases to evaluate the progress of model development
- Mechanical evaluation of defects is unsolved
- Thermomech. interaction is difficult to capture
- Academic and industrial requirements are not the same / too different
- no single solutions of complex tools, otherwise development is too expensive

Transfer and Usage:

- Definition of standards should be done close to the project start
- Use a comparable IT- infrastructure
- Use the same tool version
- Human readable exchange files simplify communication